Solid State Science and Technology, Vol. 14, No 1 (2006) 147-152
ISSN 0128-7389

OPTIMUM n-GaN SCHOTTKY DIODE CURRENT-VOLTAGE CHARACTERISTICS BY USING DIFFERENT METAL CONTACT

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ABSTRACT

We focus in this paper on the optimum room temperature (I-V) characteristics obtained by using contacts of various single layer metal (Pt, Ni, Au, Ti, Al, Sc) to form an n-type GaN schottky diode. The simulated current was obtained by increasing forward bias from 0~ 4Volt conducted by using Atlas/Blaze developed by Silvaco. The incomplete ioniz, cvt, Fermi, Bgn, Shockley- Read Hall model was used to get optimum current –voltage (I-V) characteristics. It was found that metals Pt, Ni, Au exhibit strong rectifying behavior while Al and Ti exhibit weak rectifying properties. It was also found that an increase in the metal work function is correlated with an increase in the barrier height. By calculating the values of barrier height (ϕ_B), ideality factor (η), breakdown voltage (V_B) for the different electrodes, we came to a conclusion that Pt metal exhibit optimum (I-V) rectifying characteristics of n-GaN schottky diode [7].

INTRODUCTION

The wide-band gap GaN and related materials have been extensively investigated in recent years due to their exciting application in visible and ultraviolet (UV) laser and light emitting diodes (LEDs), field-effect transistors (FETs) for high-temperature and high-power electronics. These exciting application present numerous challenges in making high-performance metal contact to GaN –based materials, which is crucial for device performance [1]. In this work we report on a comprehensive study of the contact characteristics of metals (Pt, Ni, Au, Ti, Al, Sc) to n-type GaN. The room temperature current –voltage (I-V) characteristics of all these metals are presented. Each inserted metal was in contact with the GaN interface. The electron transport of each diode was governed by the nature of the inserted metal. The leakage current depends on the metal work function or barrier height. Therefore metal-semiconductor system with higher schottky barrier height is more frequently applied [2]. The barrier height depends on the metal work function or the electro negativity of the contacting metal [3]. Until recently only a handful of metals including Pd, Ni, Cr, and Ti have been used for schottky contacts on GaN.

SIMULATION OF n-GaN SCHOTTKY DIODE

The diode is designed on lightly doped of thin epitaxial layer that is grown on heavily doped n+GaN. The lightly doped region is to be used for the junction while the heavily doped region is to minimize series resistance. In designing GaN Schottky diode, it is

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important to obtain the high breakdown voltage and low on-state voltage drop with short switching time. This paper describes application of Atlas device simulation of the wide band gap semiconductor GaN schottky diode. Simulation of GaN structure with the cylindrical symmetry diode was performed using the 2D numerical simulator [4]. The structure of GaN schottky diode is shown in Fig.1 while critical parameters [5] used for the simulation is given as in table 1. For schottky diode the following model were chosen for simulation incomplete ioniz, cvt, Fermi, Bgn and Shockley- Read Hall model. [4]

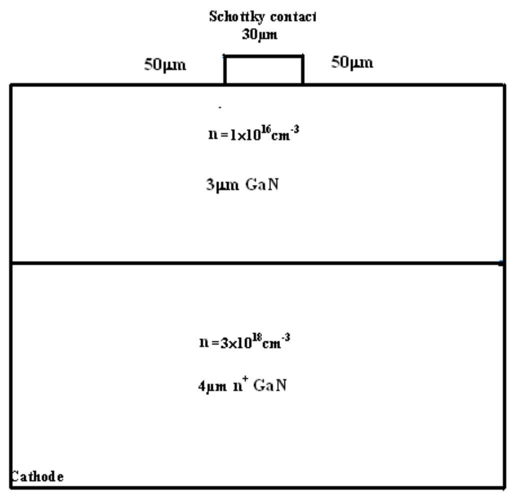

Figure 1: Structure of GaN Schottky diode.

Table 1: Important parameters in Simulation [5].

Material	Property	Value
GaN	Relative Permittivity	8.9
	Energy band gap	3.40 [ev]
	Electron affinity	4.1ev
	Saturation velocity	1.5×10^{7}
	Electron mobility	1000 [cm^2v/s]

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RESULTS AND DISCUSSION

The barrier heights and ideality factors of each metal were determined using thermionic emission theory given by

$$I=I_s\,[e^{qv/\eta kT}-1)]. \qquad (1)$$

While

$$I_s=AA^*T^2\exp\,(-q\phi_B\,/\,kT) \qquad (2)$$

Hence

$$\phi_{B\,=\,KT/q}\ln\,(A^*T^2/\,I_s) \qquad (3)$$

Where I_s is the saturation current, η is the ideality factor, T is the measurement temperature, v is applied voltage, $A^* = 24A/cm^{-2}K^{-2}$ is the effective Richardson constant for n-GaN, A is the area of contact, $k = 1.38\times10^{-23}\ JK^{-1}$is Boltzman-constant, $q=1.6\times10^{-19}$ C electron charge, ϕ_B is the barrier height [6]. The diode junction quality is quantified using its ideality factor η. The ideality factor is calculated from the bias regime where the effect of the series resistance is negligible. It can be calculated as follows,

$$\eta\ = q/kT^*V/\ln\,(I/I_s) \qquad (4)$$

The room temperature forward-bias linear I-V characteristics for each metal are shown in Figure 2. The metals Pt, Ni, Au show high non linearity, while the metals Ti, Al shows slight non-linearity. The metal Sc shows high linearity of the I-V characteristics suggesting their potential use in forming high quality ohmic contact, while Pt shows high non-linearity which displayed strong rectifying behavior which makes it potentially useful for high quality schottky contact.

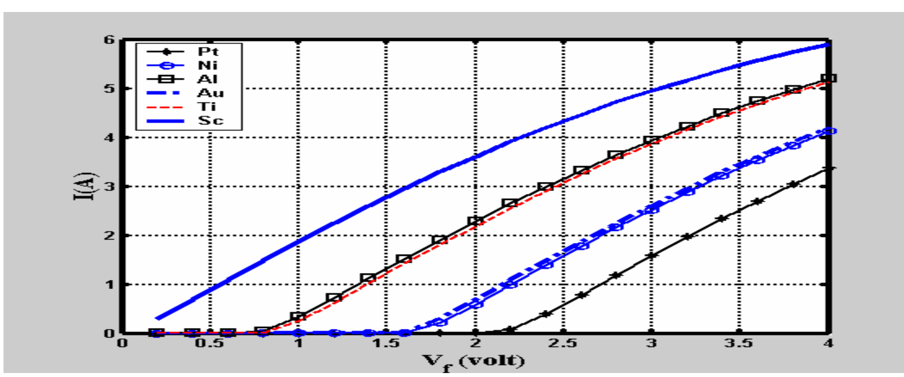

Figure 2: Forward (I-V) characteristics.

The forward I-V characteristics of these metals contacts on n-GaN are plotted on a Log scale in Figure 3 to emphasize their exponential behavior. The exponential I-V behavior is indicative of a Schottky barrier contact. The Pt metal shows high exponential behavior as compared to other metals.

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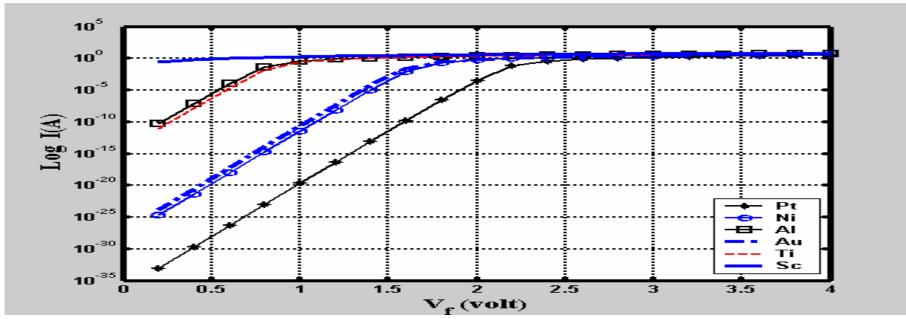

Figure 3: Forward Log I vs V characteristics.

Ideality factor is a number which characterizes the slope of a current-voltage plot as measured on a semi-logarithmic scale in Figure 3. By calculating the ideality factor of different metals we found that platinum metal shows ideal value of 1.01, while other metals shows ideality factor greater then 1. A lower slope corresponds to a higher ideality factor. The contact characteristics depend on the metal work function in which the contact go from being ohmic to schottky as ϕ_m becomes larger [7]. As seen in Fig 4 a monotonic increase in barrier height is observed as metal work function is increased. This dependence has been attributed to the ionic nature of GaN [8]. However, the increase does not scale with the work function as expected from the relation [8]

$$q\phi_B = q\phi_m - qx. \qquad (5)$$

Where ϕ_m and x are the metal work function and semiconductor electron affinity. The electron affinity of GaN has been determined to be 4.1ev. This indicates that the schottky barrier height on n-GaN is also influenced by other factors besides metal work function, which may include surface states and process-induced defects
etc [9]. It was found that an increase in metal work function correlated with an increase in the barrier height. The measured barrier height is varies significantly with different authors due to different conditions of doping, structures, measurement techniques and fabrication techniques [7].

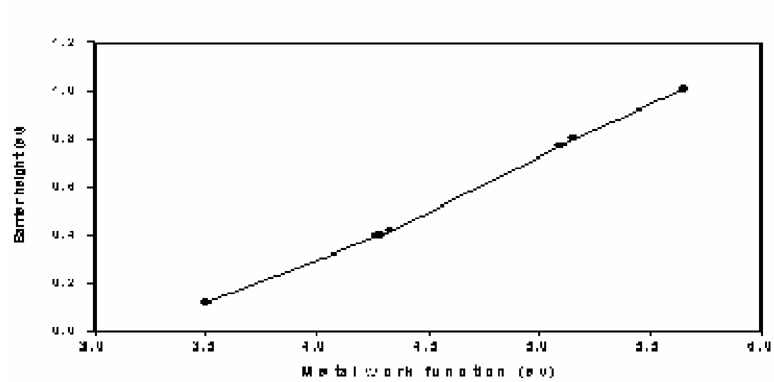

Figure 4: Relation of barrier height to metal work function.

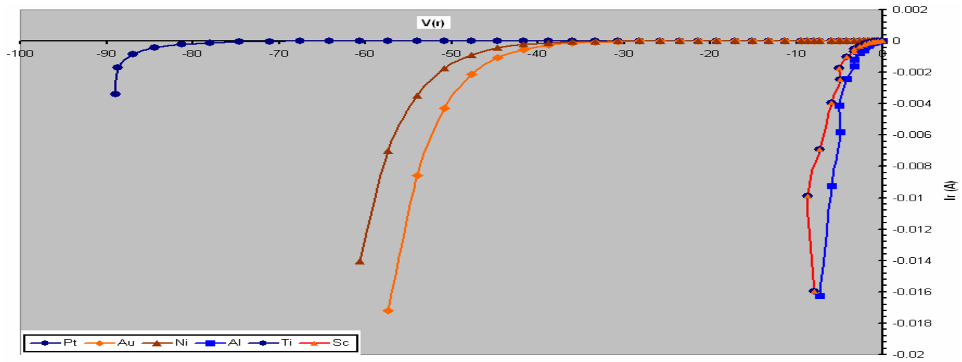

Figure 5: Reverse (I-V) characteristics.

The reverse-bias I-V characteristics of these metals are shown in Figure 5. The breakdown voltage obtained for the metals Pt, Ni, Au, Ti, Al, Sc are 89V, 59, 54, 6, 5 and 3 Volt respectively. By comparing the reverse bias I-V characteristics of these metals we found that Pt metal shows the higher breakdown voltage and lower reverse leakage current as compared to the other metals. As the metal work function ϕ_m increases the breakdown voltage of metals increases while the reverse leakage current decreases.

Table 2: Summary of measured parameters for Pt, Ni, Au, Ti, Al and Sc [7].

Metal	Metal workfunction (eV)	Barrier height (eV)	Ideality factor η	Breakdown voltage (V)
Pt	5.65	1.004	1.01	89
Ni	5.15	0.80	1.14	59
Au	5.10	0.77	1.25	54
Ti	4.33	0.42	1.68	6
Al	4.28	0.40	1.67	5
Sc	3.50	0.12	6.45	3

This comprehensive study of all these metals on the same epilayer is invaluable for proper understanding of how each metal affects the contact characteristics.

CONCLUSION

The room temperature I-V characteristics of different metals on the same epitaxial layer of n type GaN with carrier concentration 1×10^{16} cm^{-3} have been investigated. The forward bias (I-V) characteristics of Pt, Ni, and Au exhibited strong rectifying behavior, while the metals Al, Ti, show slight rectifying behavior. The metal Sc shows a linear behavior. The schottky barrier height, ideality factor, breakdown voltage were extracted from I-V characteristics. From this data, we came to a conclusion that Pt metal shows the optimum rectifying behavior with barrier height of 1.004eV, ideality factor 1.01, and maximum breakdown voltage 89V as compared to the other metals. The barrier height on n-GaN increases monotonically, but does not scale proportionately, with increasing metal work function, assuming surface states density on n-GaN. This comprehensive report should be useful in device design on n-GaN Schottky diode.

ACKNOWLEDGEMENT

This work was conducted under IRPA RMK-8 Strategic Research grant. The support from University Sains Malaysia is gratefully acknowledged.

REFERENCES

[1]. Liu, Q. Z. and Lau. S. S. (1998); *Solid-state Electronics.* **42**, 677.
[2]. Mariusz Sochacki, Adam Kolendo, Jan Szmidt, Aleksander Werbowy. (2005); *Solid-State Electronics.* **49**, 585.
[3]. Suparna Pal, Takashi Sugino. (2000); *Applied surface Science.* **161**, 263
[4]. Silvaco international. (2000); Device simulation software. **2**, 84
[5]. Chung, S.W. Hwang, W.J. Chin C, Lee. Shin, M.W. (2004); *Journal of Crystal Growth.* **268**, 607.
[6]. Lee,K.N.Cao,X.A..Abernathy, C.R. Pearton, S.J.Zhang, A.P..Ren, F.Hickman, R Van Hove, J.M. (2000); *Solid-State Electronics* **44**, 1203
[7]. A.C. Schmitz, A.T. Ping, M.Asif khan, Q.Chen, J.W. Yang, I.Adesida. (1998); *Electronic Material*. **27**, 4.
[8]. Mott, N. F. (1938); *Proc. Camb Phil Soc.* **34**, 568.
[9]. John Bardeen. (1947); *Phys. Rev.* **71**, 717.